P3.2 THE MERGER OF OPTRAN AND RTTOV

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1. INTRODUCTION

Over the last few years preliminary comparisons have been made between OPTRAN (McMillin et al., 1995) and RTTOV (Saunders et al., 1999). These comparisons indicated that RTTOV fitted the line-by-line (LBL) radiances better for uniformly mixed gases, while OPTRAN fitted the line-by-line radiances better for water vapor. These comparisons were not complete in the following respects: 1) different infrared line-by-line models were applied: RTTOV used GENLN2 (Edwards, 1992) but OPTRAN used LBLRTM (Clough and Iacono, 1995); 2) different sets of dependent atmospheres were used; and 3) OPTRAN did not have an adequate independent set of transmittances with which to compare. In the summer of 2001 the author visited the Met Office in Bracknell UK under the auspices of the Satellite Application Facility for Numerical Weather Prediction. The purpose of this visit was to merge OPTRAN and RTTOV-6 while addressing the limitations of the earlier comparisons. This report documents some of the results of that work.

2. STRUCTURE OF THE ORIGINAL CODES

Most fast radiative transfer models use some form of multiple linear regression to predict atmospheric propagation properties from atmospheric state parameters such as temperature, moisture, pressure and ozone. RTTOV predicts optical depth on fixed pressure levels. Figure 1 illustrates the basic structure of RTTOV, neglecting low level routines. Subroutine RTTOV controls the radiative transfer calculation. It first calls PRFIN which unpacks the input atmospheric profile which in turn calls PRFTAU to compute the predictors. RTTOV then calls OPDEP to compute the optical depth, which is then converted to transmittances by routine RTTAU. Finally RTINT is called to compute the radiances and brightness temperatures.

OPTRAN predicts the absorption coefficient on fixed levels of absorber amount, the product of which is optical depth. Figure 2 depicts the basic structure of the original OPTRAN (OPTRAN2), which uses two interpolations. The atmospheric state is interpolated to absorber levels on which the regression is performed. The resulting absorption coefficients are then interpolated back to the levels of the input profile for the computation of optical depth and radiance calculation. Subroutine OPTRAN is the driver routine. It computes the absorber profile, and calls OPTRAN_SPECIES to compute the optical depth for each absorber. OPTRAN then computes the total optical depth and transmittance. OPTRAN_SPECIES determines the levels in absorber space that bracket input profile, and then calls GET_PREDICTORS_ALL to compute the predictors, and then calculates absorption coefficients in absorber space. Finally OPTRAN_SPECIES interpolates the absorption coefficients back to pressure space and computes the optical depth.

A newer version of OPTRAN (OPTRAN1) has been developed which is about 20% faster. This version interpolates the regression coefficients to the input pressure levels, thus requiring only a single interpolation. The basic layout of OPTRAN1 is shown in figure 3. OPTRAN1 is the core of the operational code presently used at NCEP/EMC (van Delst, 2002). Results of merging both versions of OPTRAN with RTTOV-6 will be presented here.

3. STRUCTURE OF THE MERGED CODES

The basic structure of the merged OPTRAN/RTTOV code is illustrated in Figure 4. The OPTRAN code was heavily modified to mimic the functional structure of RTTOV. The absorber profile computation was moved from subroutine OPTRAN to PRFIN, and subroutine OPTRAN was removed entirely. The code to determine the bracketing levels in the absorber space and the calls to GET_PREDICTORS_ALL were moved from OPTRAN_SPECIES to PRFTAU. The call to OPTRAN_SPECIES to compute the OPTRAN optical depths was moved to OPDEP. Finally, switches were placed as appropriate in the revised code to permit using either RTTOV or OPTRAN or no computation for each absorber.

While this close merging of the two codes permitted flexible operation of the forward model, it caused great difficulty in testing and diagnosing of the subsequent tangent linear, adjoint and Jacobian models. This difficulty was largely due to the conditionals involved with the switching capability, which required multiple test routines to be written for each subroutine.

4. VERIFICATION OF THE FORWARD MODELS

The OPTRAN-1 and 2 and RTTOV-6 coefficients were derived from the Met Office dependent set of 43 atmospheric profiles for temperature (Matricardi and

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Saunders, 1999), and 34 atmospheric profiles for ozone. The comparison was made with an independent set of 117 atmospheric profiles (Chevallier et al, 2000). Statistics presented here are the mean and standard deviation of the difference between the fast model and the LBL brightness temperatures for these 117 atmospheres at 5 zenith angles equally spaced in secant from 1.0 to 2.0.

5. VERIFICATION OF SEPARATE MODELS

Figure 5 gives the mean brightness temperature difference for the HIRS and AMSU-A/B on NOAA-16 for RTTOV-6, OPTRAN1 and OPTRAN2. RTTOV-6 generates a smaller mean difference for all channels except HIRS channels 2, 5, 11, 17, 18 and 19, and AMSU 2 and 4. Figure 6 shows the standard deviations of the brightness temperature differences corresponding to Figure 5. In this respect OPTRAN performs better than RTTOV-6 for channels with significant water vapor contribution: HIRS 7, 8, 10, 11, 12, 13, 19, and AMSU 1, 17, 19, 20. For all of the other channels, where the temperature signal dominates, RTTOV outperformed OPTRAN. It is unclear why OPTRAN did not perform well for AMSU channel 18, where water vapor dominates. Nevertheless these results confirm that in general OPTRAN performs better for water vapor channels, while RTTOV performs better for temperature channels.

Note that for very opaque channels, OPTRAN2 performed much better than OPTRAN1. This illustrates that some consideration that must be given to accuracy over speed in selecting which version of OPTRAN to apply.

6. VERIFICATION OF THE COMBINED MODEL

The merged model was run using three of the possible combinations: 1: OPTRAN1 for water vapor and RTTOV-6 for mixed gases and ozone, 2: OPTRAN2 for water vapor and RTTOV-6 for mixed gases and ozone, and 3: RTTOV-6 for all gases. Figures 7 and 8 give the mean and standard differences of the brightness temperature differences as compared to the independent LBL profiles. Note that the results for RTTOV applied to all gases is the same as in Figures 5 and 6. In general, the RTTOV-6 model has a similar or smaller mean difference than the OPTRAN/RTTOV model. However, the standard deviation of the OPTRAN/RTTOV model was smaller for all channels except HIRS 9,15, 16, 17 and AMSU 15, 16 and 18.

7. JACOBIAN COMPARISONS

Figures 9 and 10 show the temperature and water vapour Jacobians respectively for NOAA-16 HIRS and AMSU channels computed using the Jacobian code on independent atmosphere 116. Only the OPTRAN1 version of the combined code is available in Jacobian form. The OPTRAN and RTTOV-6 temperature Jacobians are very similar, with only small differences in HIRS 10 and 12, and more significant differences in HIRS 19.

The HIRS water vapour Jacobians in Figure 10 are quite different for OPTRAN and RTTOV-6, which explains the different performance in fitting the LBL data. The AMSU water vapour Jacobians in Figure 10 are much more similar. Given the large differences between OPTRAN and RTTOV in the fit to the LBL data for AMSU channel 18 as shown in Figures 6 and 8, the similarity of the Jacobians is perplexing.

8. STATUS OF THE COMBINED CODE

The combined OPTRAN1/RTTOV code is complete for the forward, tangent linear, adjoint and Jacobian models. The OPTRAN2/RTTOV code is complete for the forward model only. Coefficients have been generated from the MetOffice dependent atmospheres for the HIRS and AMSU-A/B on NOAA-15 and NOAA-16.

9. TIMING

Timing runs were made with the combined forward model code on an unburdened workstation. Three cases were run, RTTOV-6 by itself, OPTRAN-1 by itself, and OPTRAN-1 for water vapour, and RTTOV-6 for mixed gases and ozone. The OPTRAN-1 code was 39% slower than the RTTOV-6 by itself. The combined OPTRAN/RTTOV code was 13% slower than RTTOV-6 by itself, which suggests a linear effect of adding additional gases in OPTRAN. These numbers do not include the penalty of interpolating a NWP model profile to the RTTOV levels, and as such are an overstatement of the cost of including OPTRAN in the radiative transfer computation. This will be discussed further below.

10. DISCUSSION

Although this paper describes what appears to be a 'clean' inter-comparison of the OPTRAN and RTTOV code, there is a subtle difference in the use of these codes which is not yet resolved. In this comparison, the dependent and independent LBL profiles were on the fixed RTTOV standard pressure levels, so that no interpolation was required for RTTOV. However, when these models are used in an NWP analysis, the NWP state vector must be interpolated to the RTTOV levels. OPTRAN always performs an internal interpolation. A truly fair test would use independent atmospheres with arbitrary pressure levels, so as to assess the impact of interpolation error as well as radiative transfer error.

11. SUMMARY

This paper describes an experiment in combining the OPTRAN and the RTTOV-6 codes. When the OPTRAN methodology for water vapor is combined with the RTTOV methodology for mixed gases and ozone, the result is an overall better fit to the radiances for both the HIRS and the AMSU channels. The combined OPTRAN1/RTTOV-6 code has been delivered to the MetOffice, and is available from Roger Saunders (roger.saunders@metoffice.com).

12. REFERENCES

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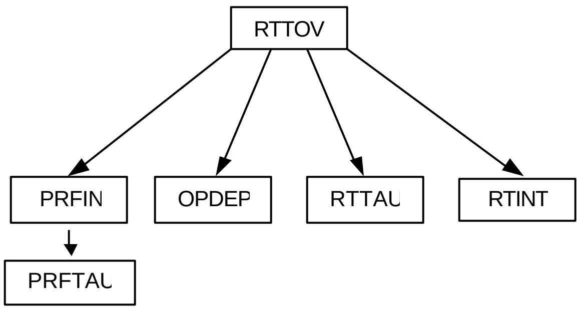


Figure 1: Structure of original RTTOV code

RTTOV
Calls PRFIN to unpack state vector
Calls OPDEP to compute optical depths
Calls RTTAU to compute transmittances
Calls RTINT to compute radiances and brightness temperatures

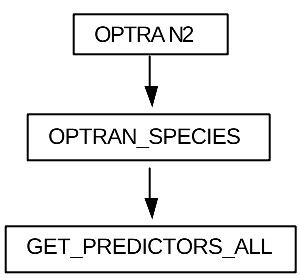
PRFIN
Unpacks input state vector
Calls PRFTAU to compute predictors

PRFTAU
Computes predictors

OPDEP
Computes optical depth

RTTAU
Computes transmittances

RTINT
Integrates the radiative transfer equation to produce radiances and brightness temperatures

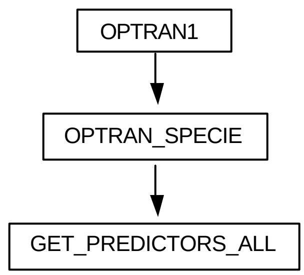


Transmittance Driver.
Set up coefficients on first invocation.
Compute absorber profile.
Call OPTRAN_SPECIES to compute optical depths.
Compute transmittances from optical depths.

Find levels in absorber space that bracket input profile.
Call GET_PREDICTORS_ALL to compute predictors.
Compute absorption coefficients in absorber space.
Interpolate absorption coefficients to pressure space.
Compute optical depth in pressure space.

Compute predictors in absorber space.

Figure 2. Structure of two interpolation OPTRAN code



Transmittance Driver.
Set up coefficients on first invocation.
Compute absorber profile.
Call OPTRAN_SPECIES to compute optical depths.
Compute transmittances from optical depths.

Find levels in absorber space that bracket input profile.
Call GET_PREDICTORS_ALL to compute predictors on pressure levels.
Compute absorption coefficients by interpolating regression coefficients from absorber space to pressure space
Compute optical depth in pressure space.

Compute predictors in pressure space.

Figure 3. Structure of single interpolation OPTRAN code

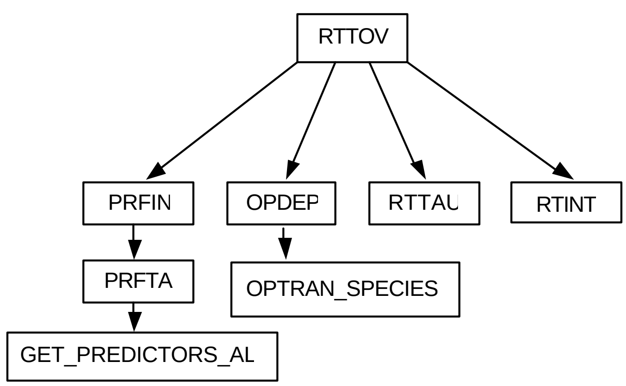


Figure 4: Structure of combined OPTRAN and RTTOV code

RTTOV
Calls PRFIN to unpack state vector
Calls OPDEP to compute optical depths
Calls RTTAU to compute transmittances
Calls RTINT to compute radiances and brightness

PRFIN
Unpacks input state vector
Computes absorber profile (vice OPTRANS)
Calls PRFTAU to compute predictors

PRFTAU
Computes predictors.
Find levels in absorber space that bracket input profile (vice OPTRANS_SPECIES).
Calls GET_PREDICTORS_ALL.

OPDEP
Computes optical depth
Calls OPTRANS_SPECIES

RTTAU
Computes transmittances

RTINT
Integrates the radiative transfer equation to produce

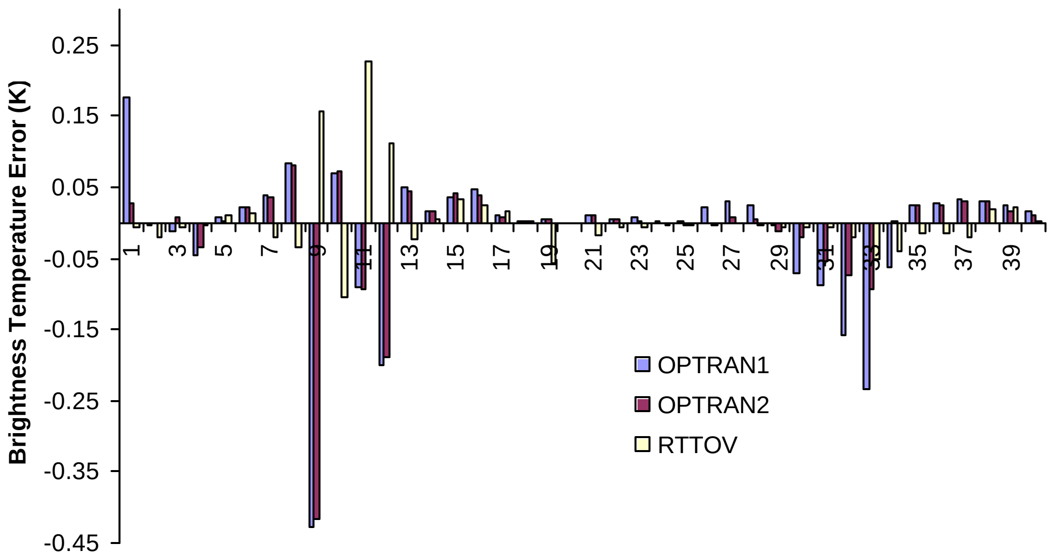


Figure 5: Mean brightness temperature difference of RT model from LBL for independent atmospheres.

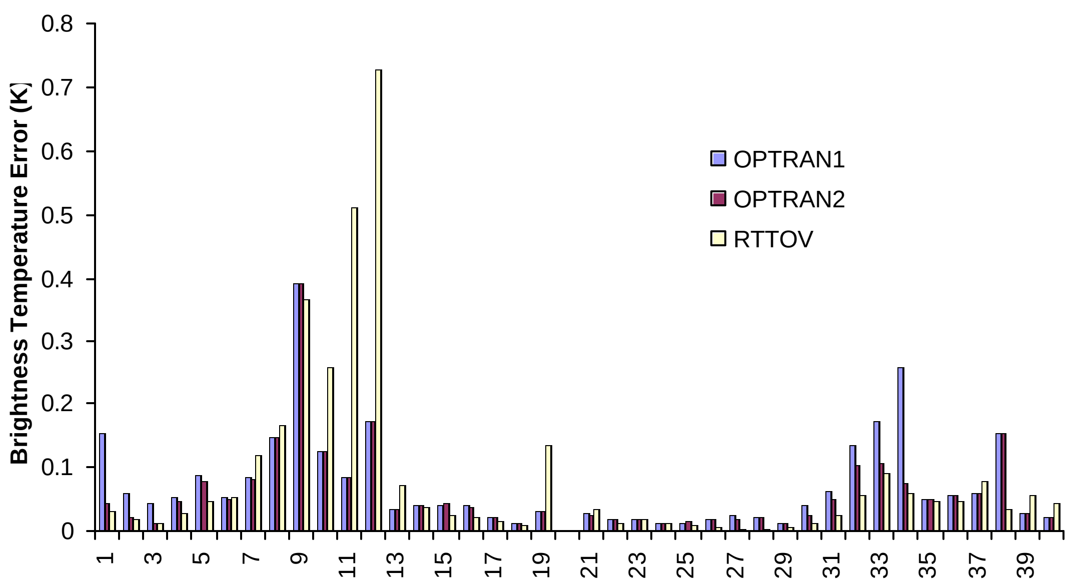


Figure 6: Standard deviation of brightness temperature difference of RT model from LBL for independent atmospheres.

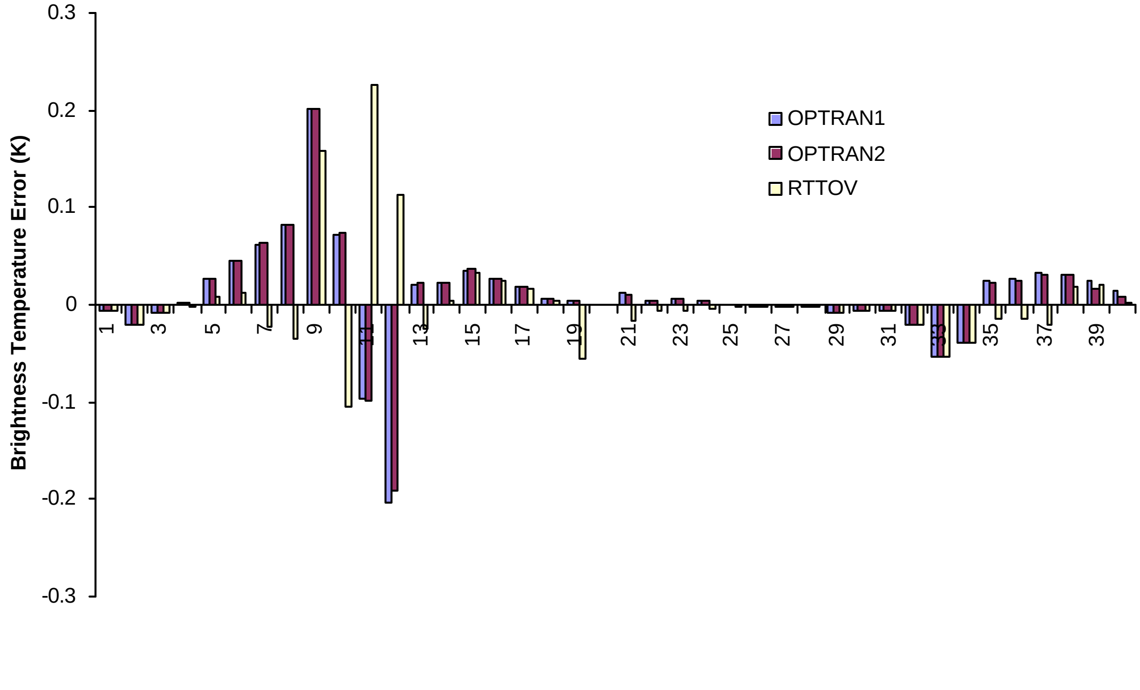


Figure 7: Independent Profile Mean Error. RTTOV-6 for uniformly mixed gases and O3, as indicated for H2O

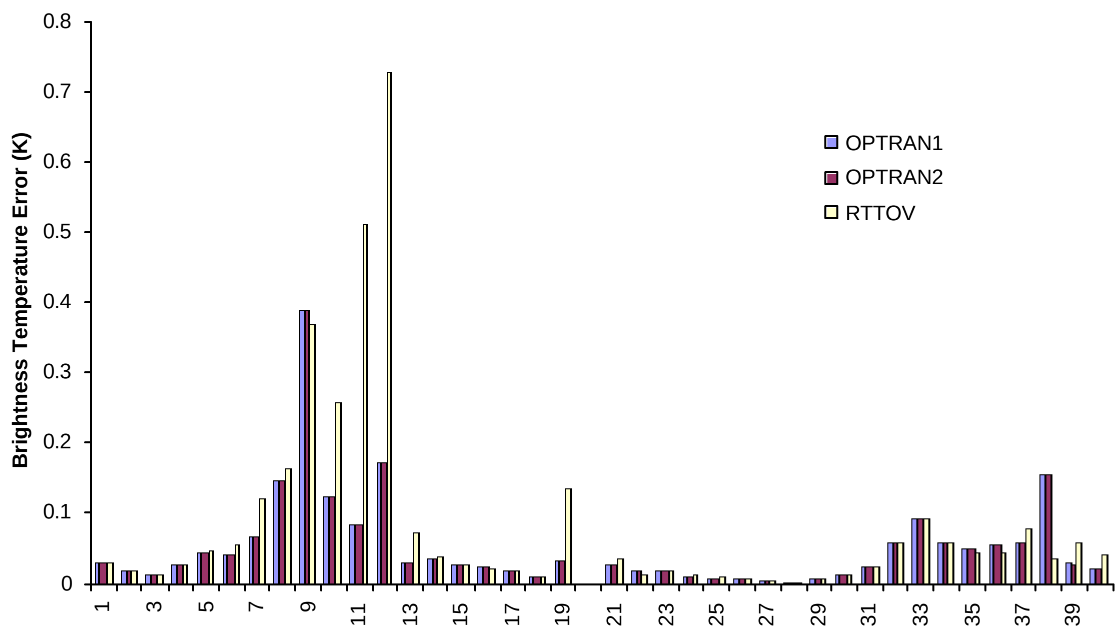


Figure 8: Independent Profile Standard Error. RTTOV-6 for uniformly mixed gases and O3, as indicated for H2O

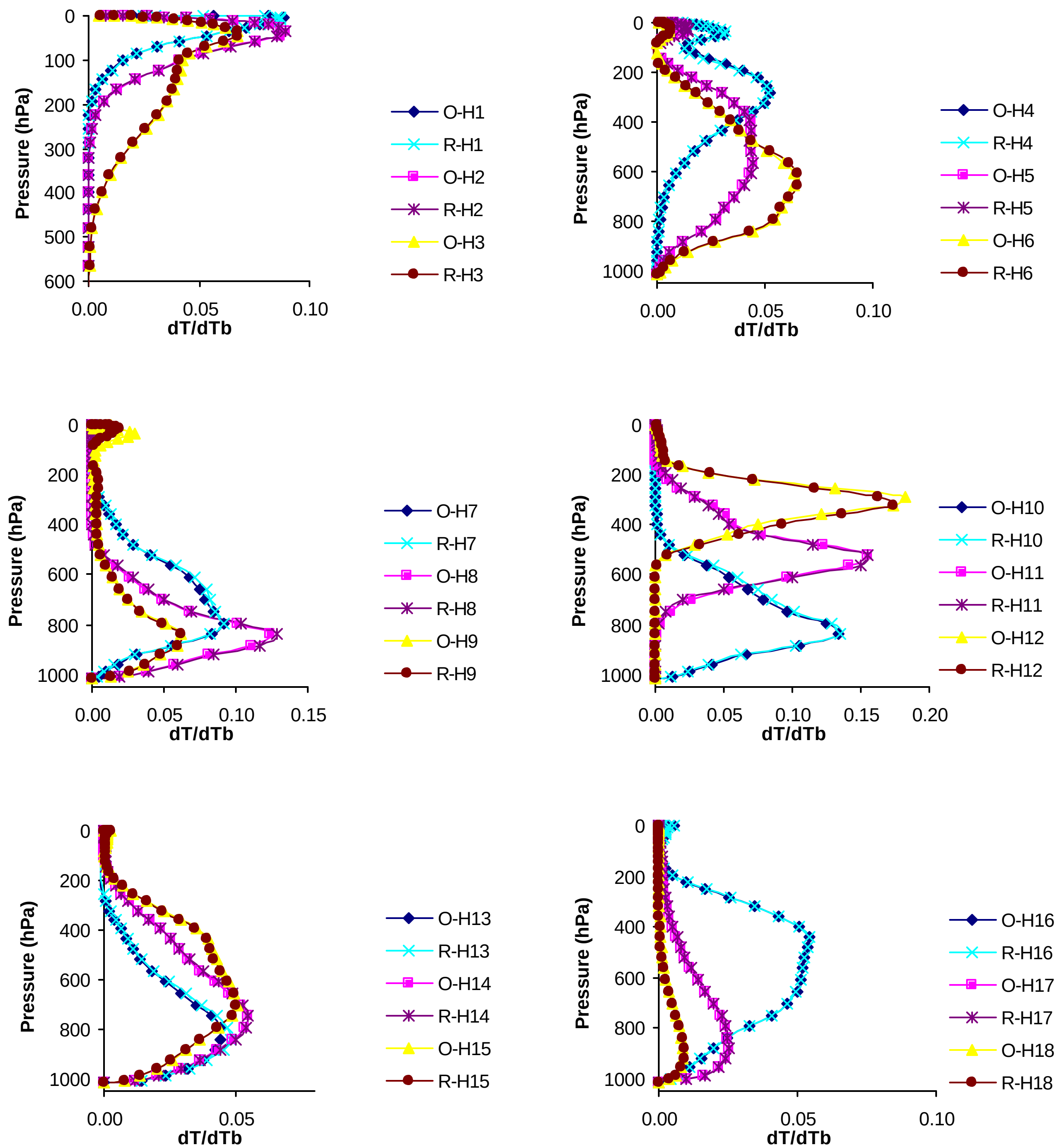


Figure 9a: NOAA-16 ATOVS Temperature Jacobians. O and R refer to OPTRAN and RTTOV respectively. H and A refer to HIRS and AMSU respectively.

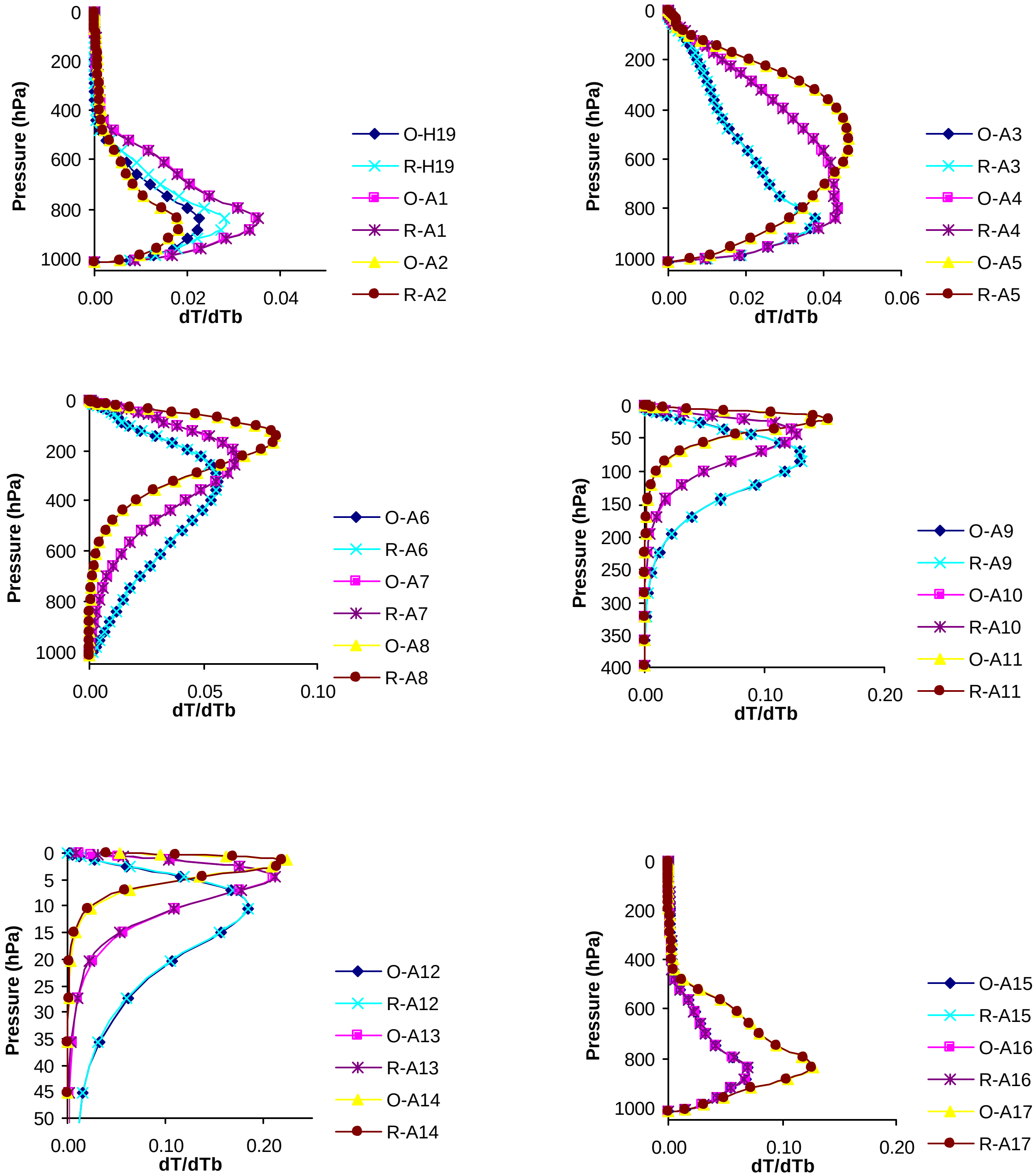


Figure 9b: NOAA-16 ATOVS Temperature Jacobians, cont.

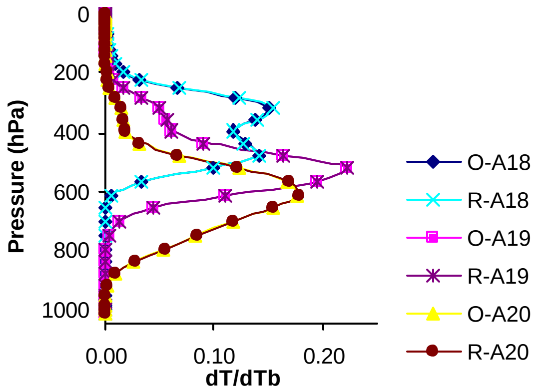


Figure 9c: NOAA-16 ATOVS Temperature Jacobians, cont.

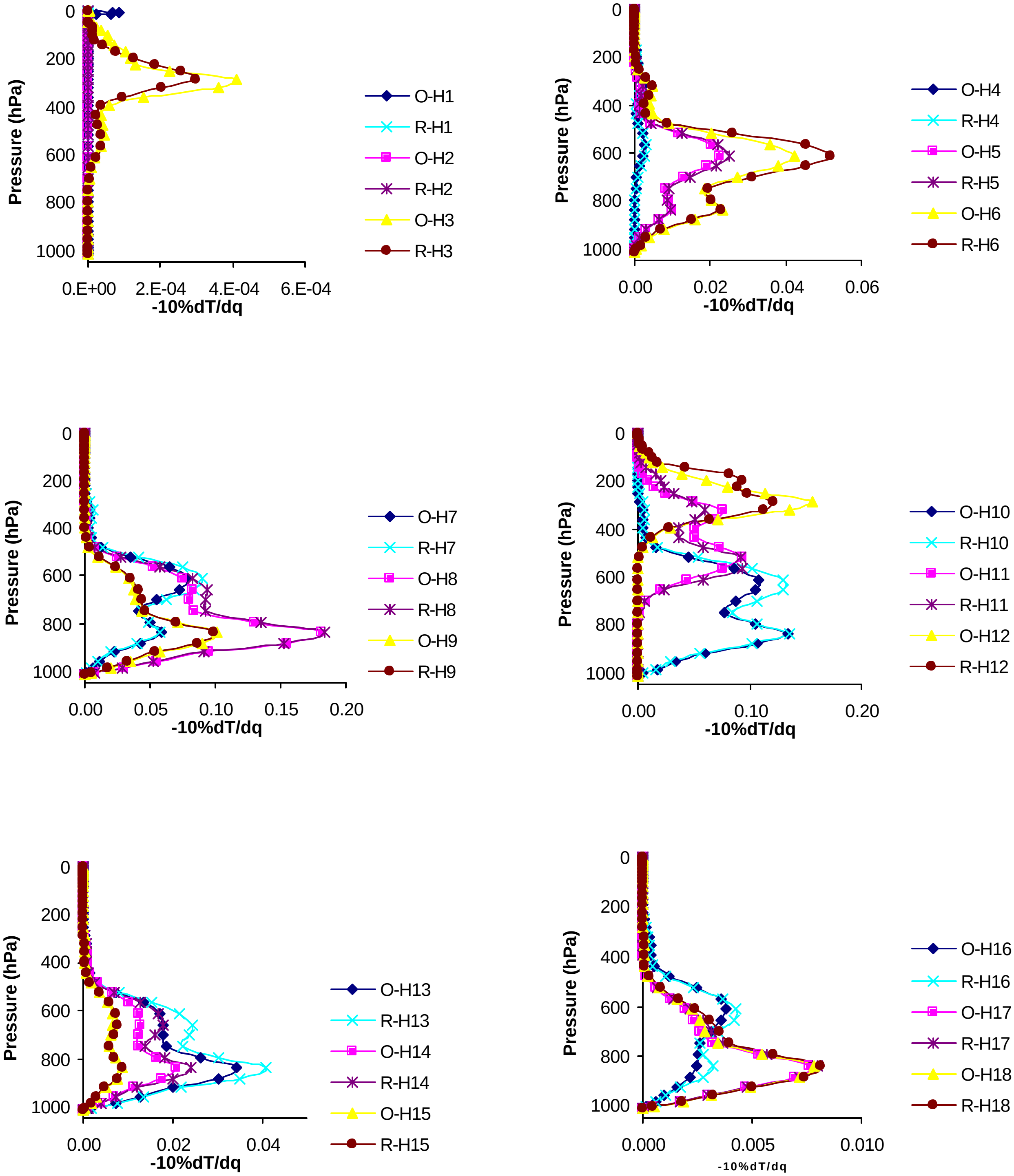


Figure 10a: NOAA-16 ATOVS Water Vapour Jacobians. O and R refer to OPTRAN and RTTOV respectively. H and A refer to HIRS and AMSU respectively.

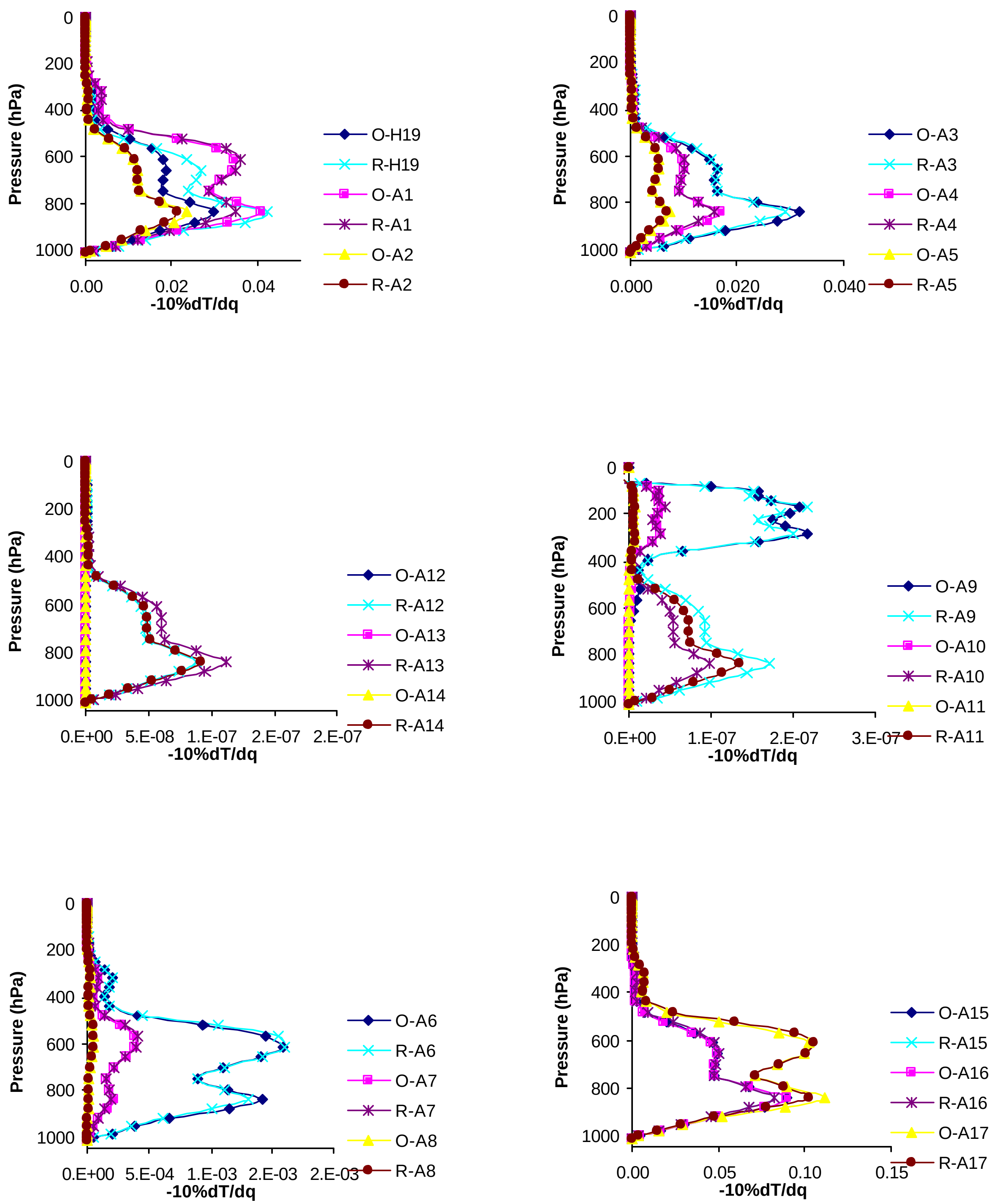


Figure 10b: NOAA-16 ATOVS Water Vapour Jacobians, cont.

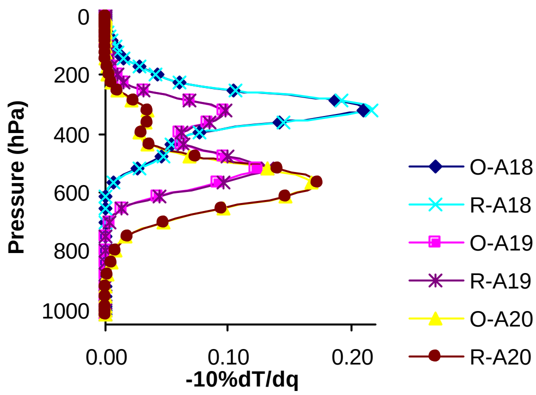


Figure 10c: NOAA-16 ATOVS Water Vapour Jacobians, cont.